Modeling and Analysis of Fixturing Dynamic Stability in Machining

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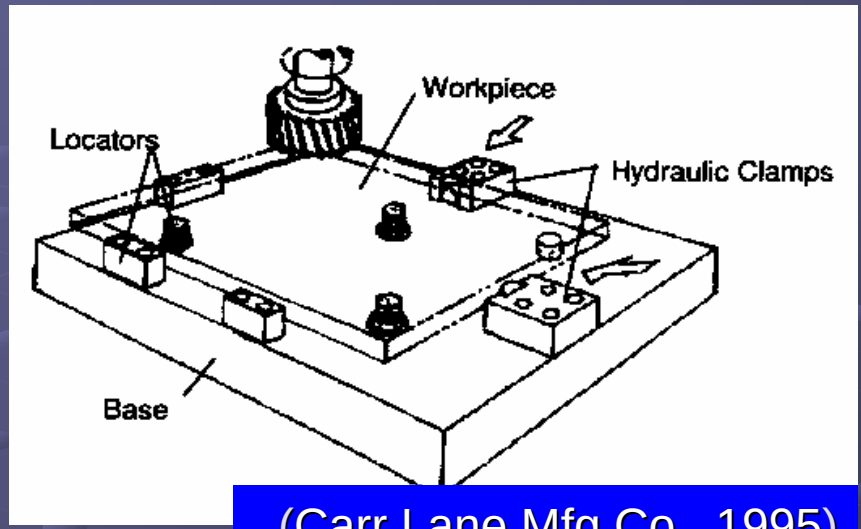
Introduction

Machining Fixture:

- Establish and maintain required position and orientation of a workpiece
- Directly affects operational safety and part quality



(Carr Lane Mfg Co., 1995)

Limitations of Previous Work:

- Majority ignores system dynamics, e.g., inertia, damping, material removal effect
- No information available on experimental investigation of fixture-workpiece dynamics during machining
- No information available on optimization of fixture-workpiece dynamics

Objectives

- Establish a mathematical procedure to analyze dynamic stability of a fixtured workpiece in machining
- Model and investigate material removal effect on system dynamic behavior
- Optimize fixture design to achieve fixturing dynamic stability
- Quantify and synthesize dynamics-induced part quality errors
- Run machining experiments to validate and refine models

Stability Analysis – Criteria

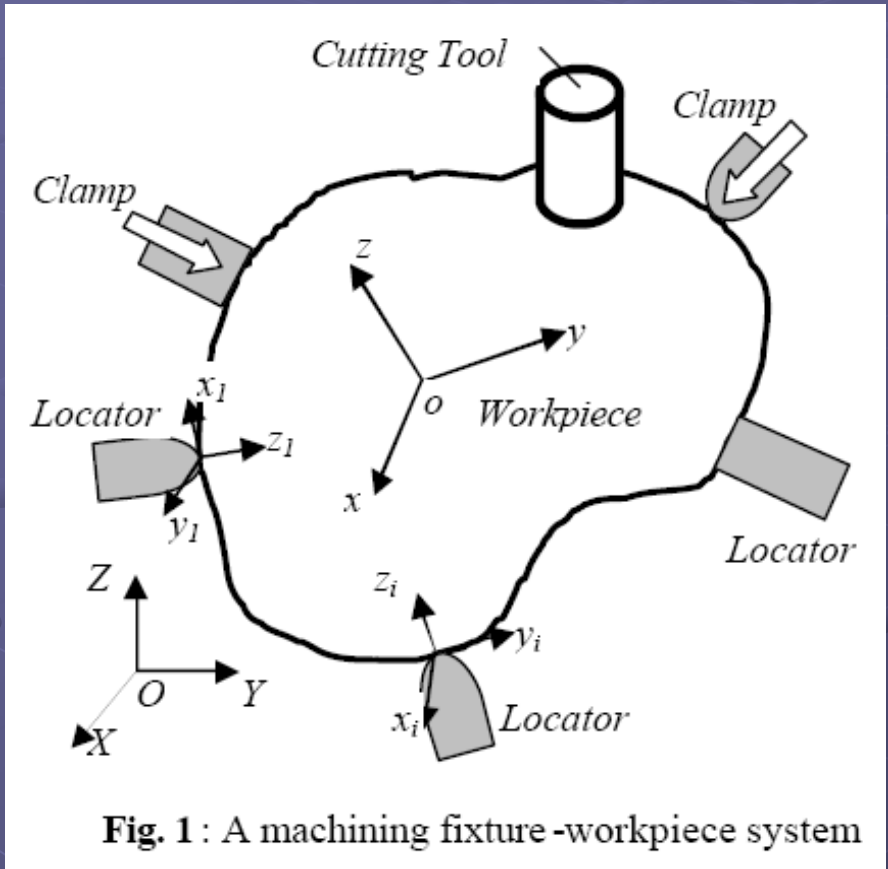
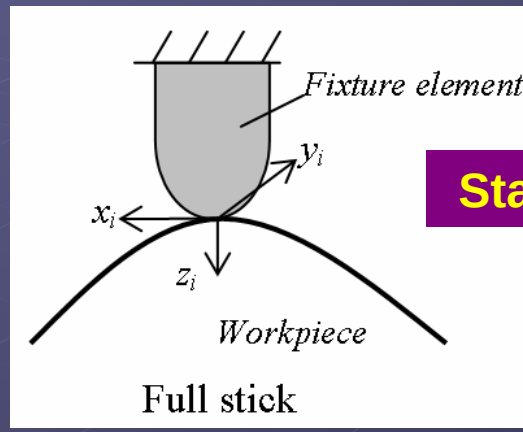
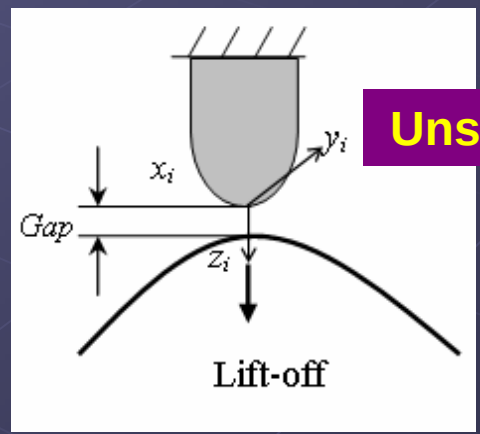


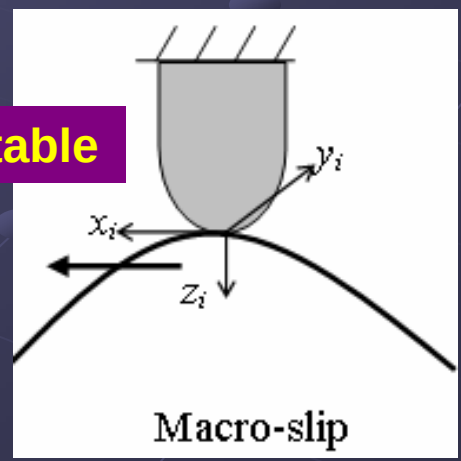
Fig. 1 : A machining fixture -workpiece system



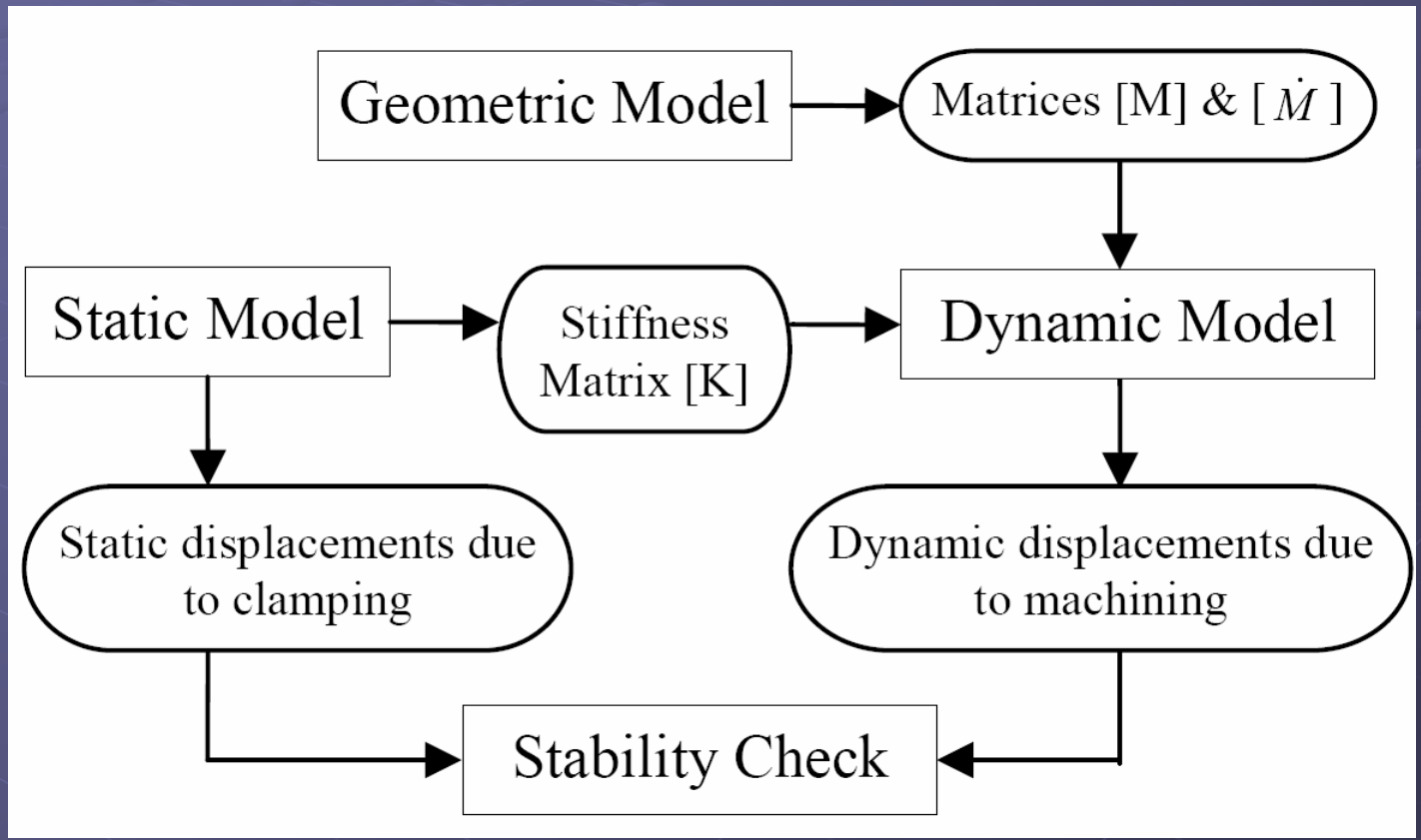
Stable



Unstable



Stability Analysis – Procedure



Stability Modeling

$$\underset{P_i,\,Q_{xi},\,Q_{yi}}{Minimize}\ \ \Pi_C(P_i, Q_{xi}, Q_{yi})$$

Subject to:

$$\sum \bar{F} = \bar{0},\ \sum \bar{M} = \bar{0}$$

$$P_j = F_{cj}$$

$$\sqrt{(Q_{xi})^2 + (Q_{yi})^2} - \mu_S^i P_i \le 0$$

$$P_i \ge 0$$

$$P_i - S_y(\pi a_i^2) \le 0$$

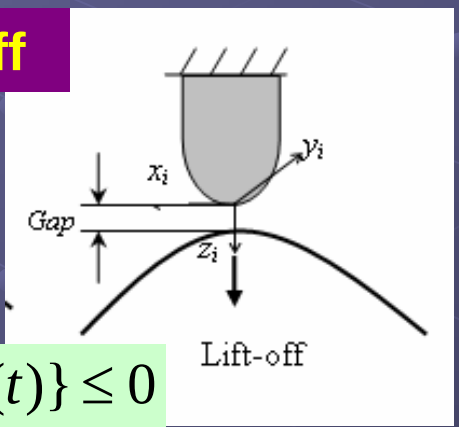
$$[M]\,\ddot{\bar{q}} + [\dot{M}]\,\dot{\bar{q}} + [K]\,\bar{q} = \bar{Q}(t)$$

Clamping Statics

Machining Dynamics

Fixturing Stability

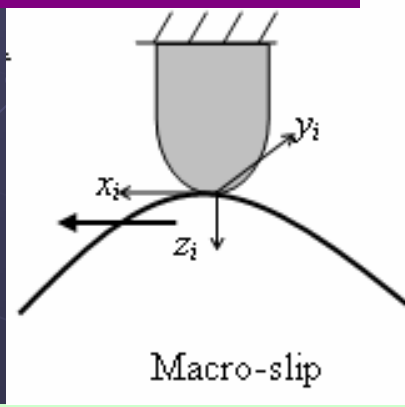
Lift-off



$$\max_t\{\Delta_{zi}(t)\} \le 0$$

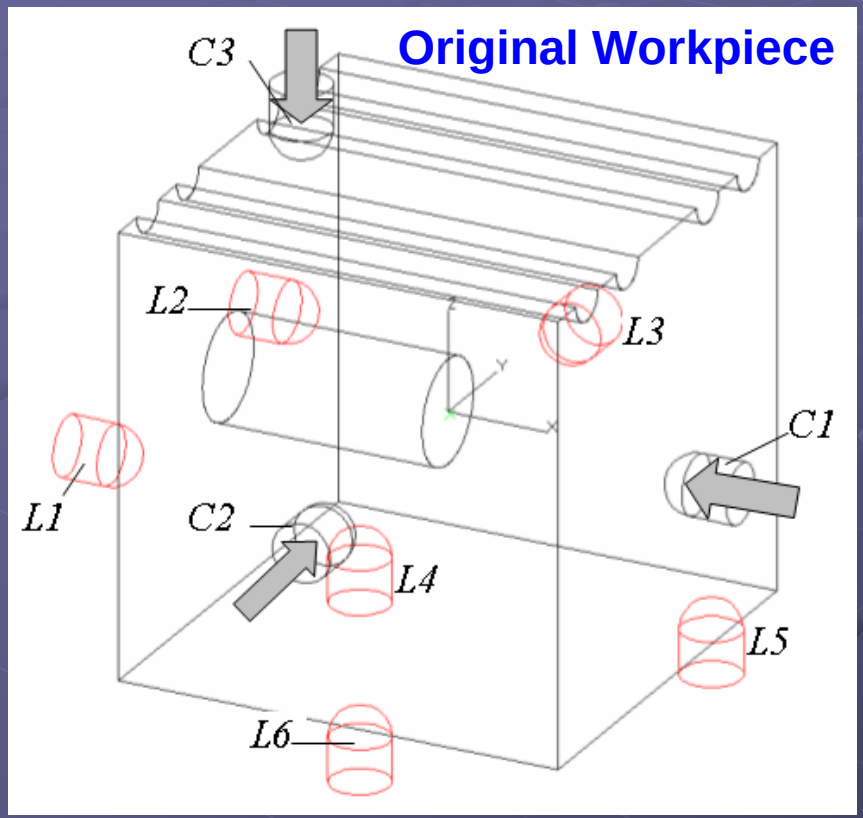
$$\Delta_{ji}(t) = d_{ji}(t) - \delta_{ji}$$

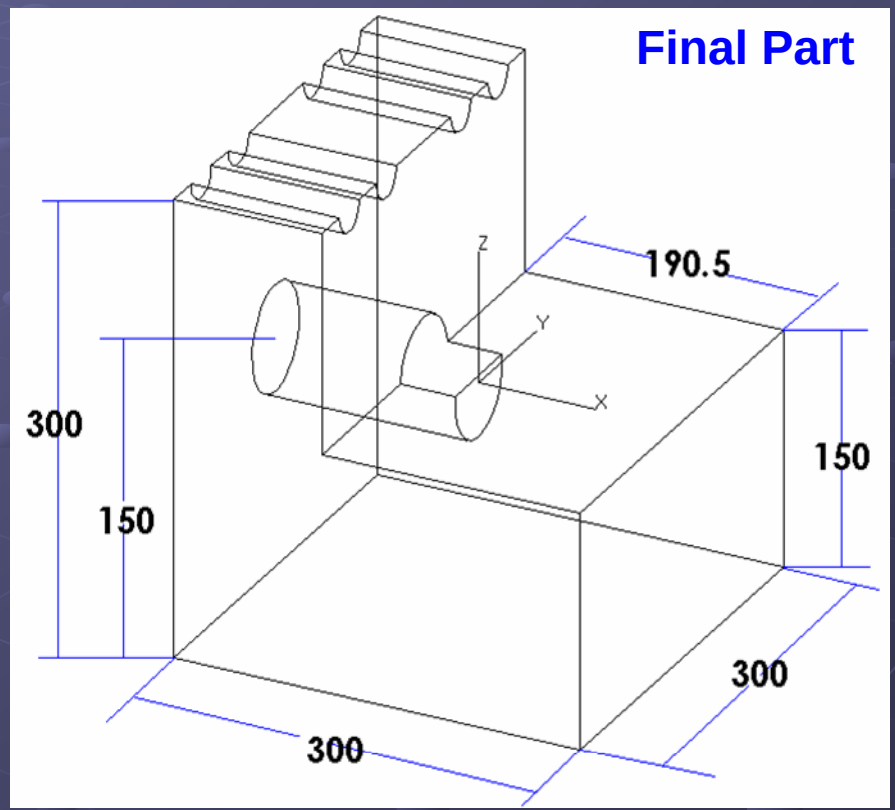
Macro-slip



$$\max_t\{\sqrt{[k_{xi}\,\Delta_{xi}(t)]^2 + [k_{yi}\,\Delta_{yi}(t)]^2} - \mu_S^i[k_{zi}|\Delta_{zi}(t)|]\} \le 0$$

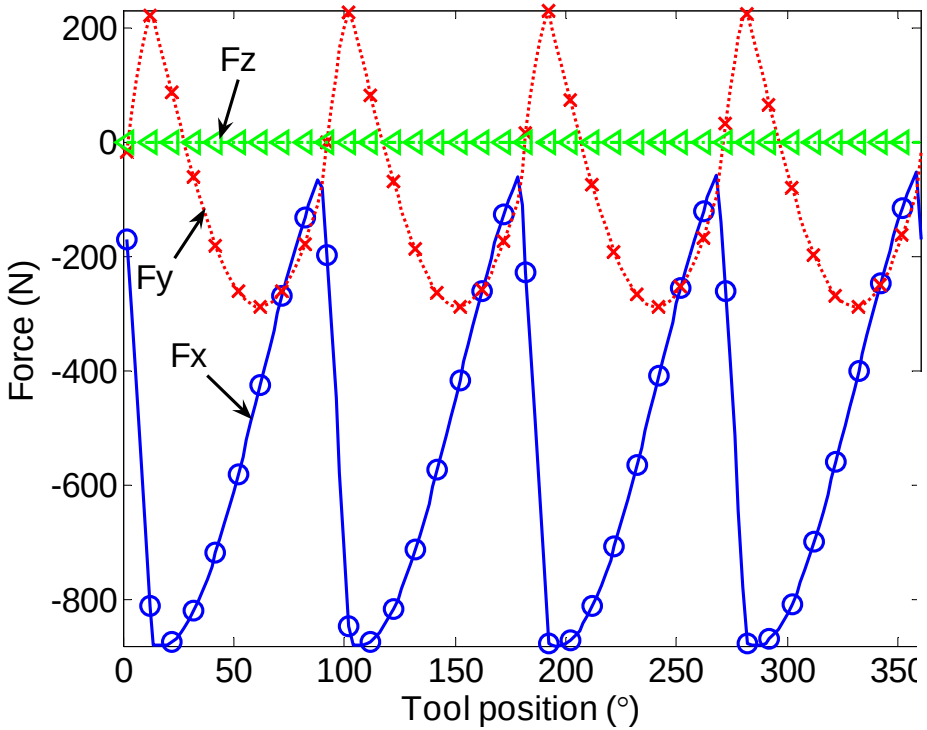
Simulation Example (1)

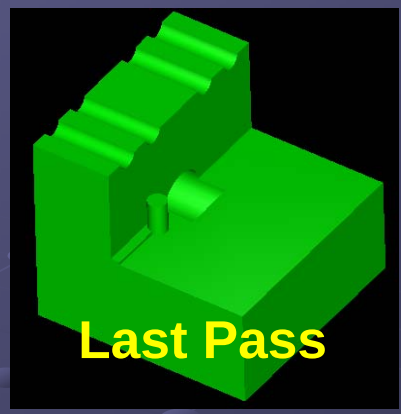




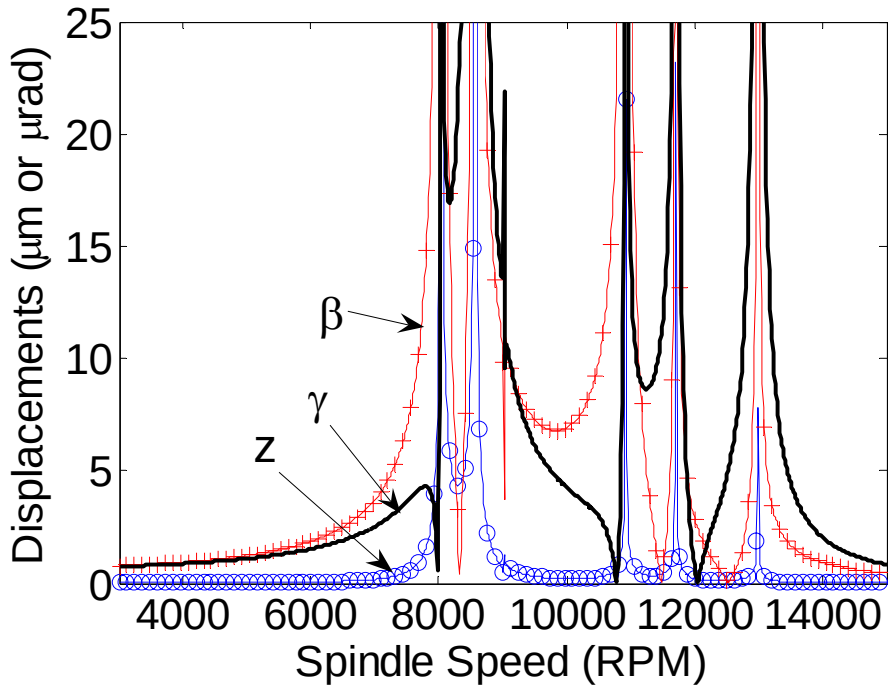
Simulation Example (2)

Cutting Forces

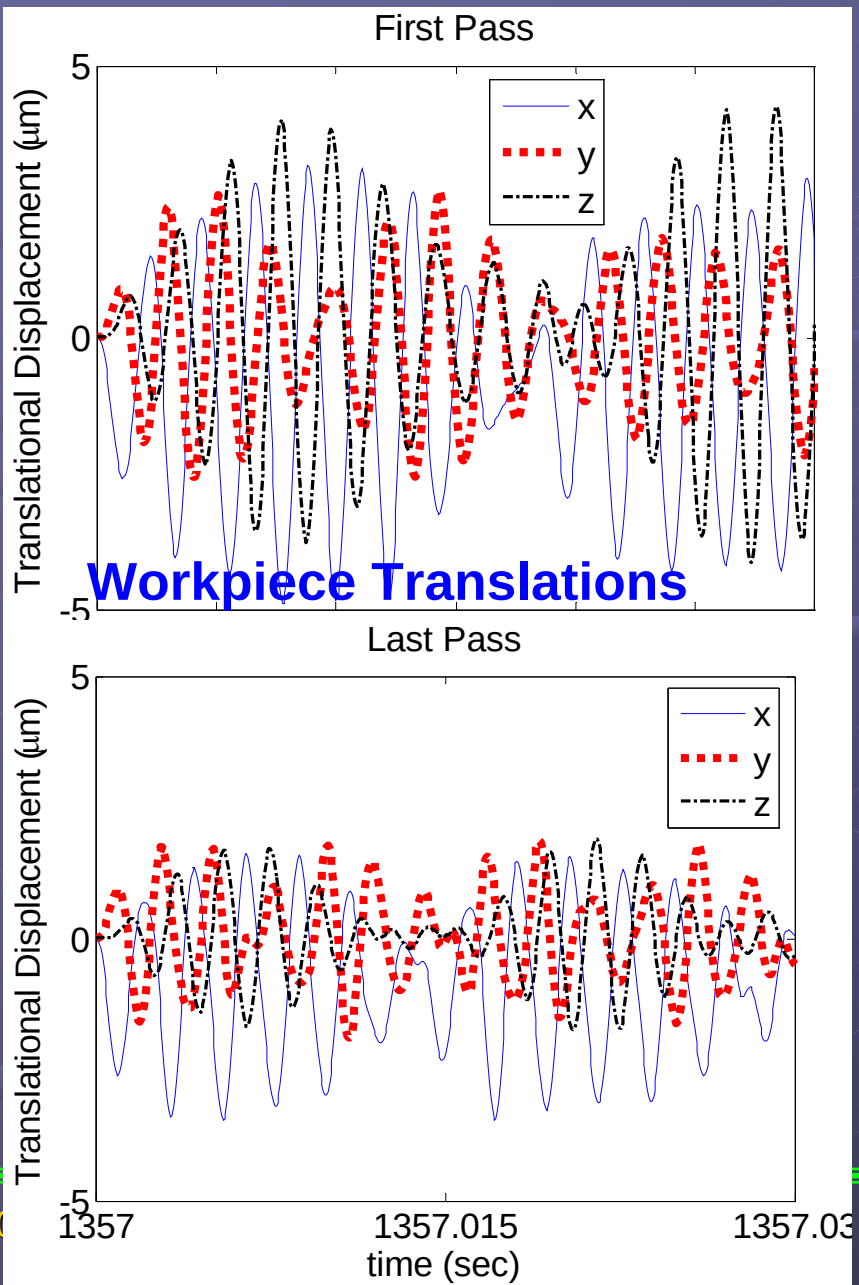


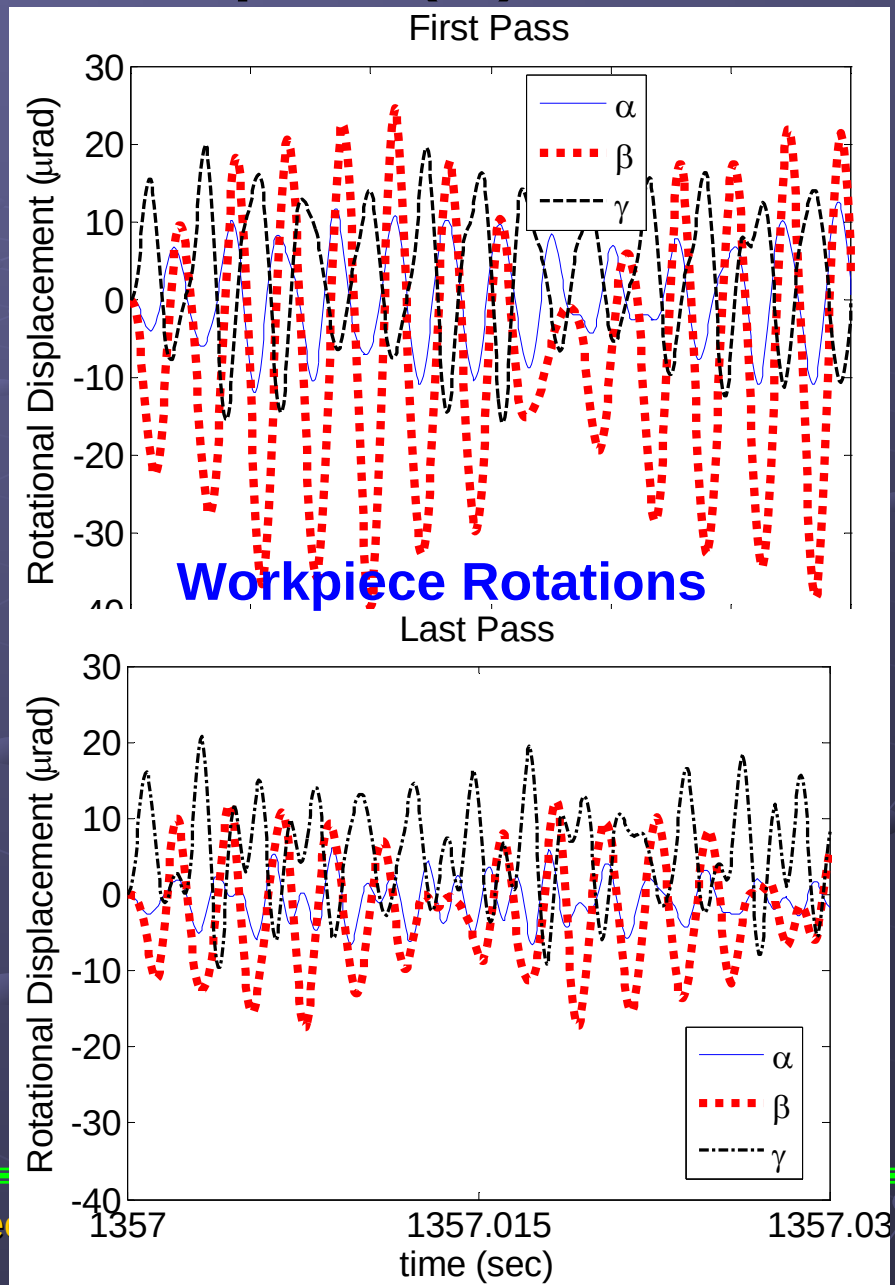


Workpiece Motion vs. Spindle Speed

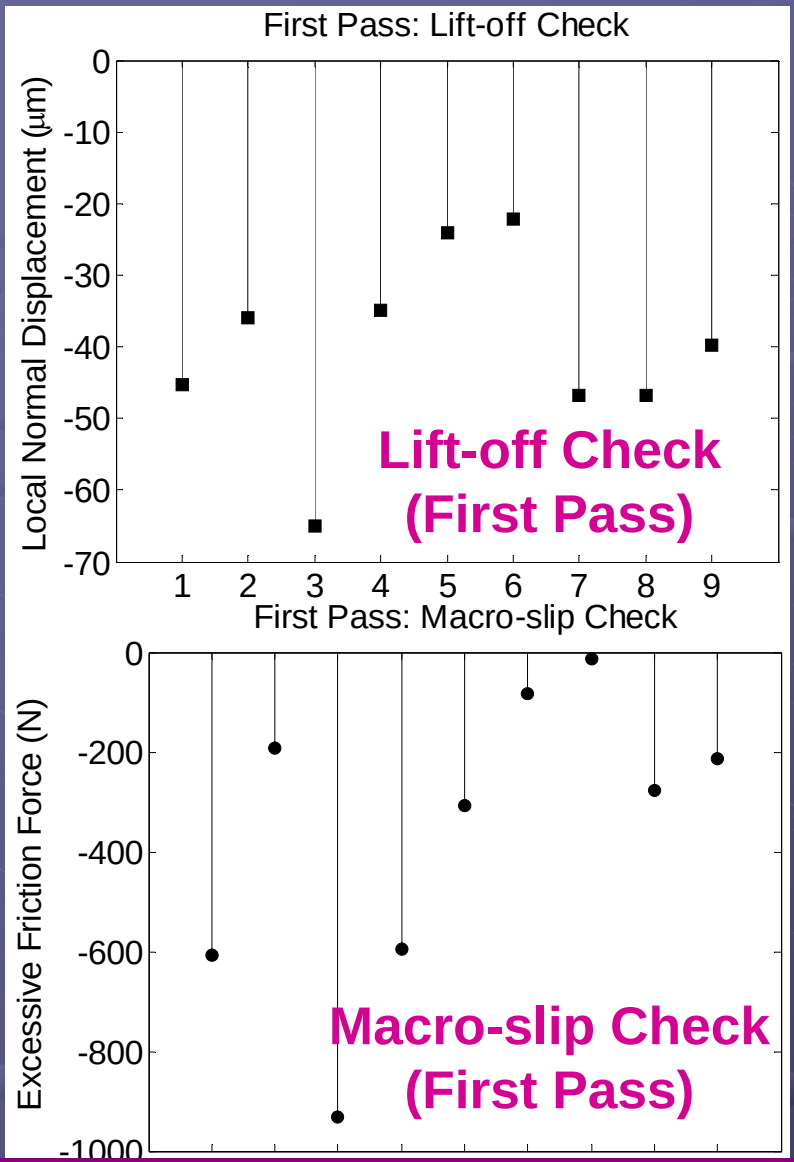


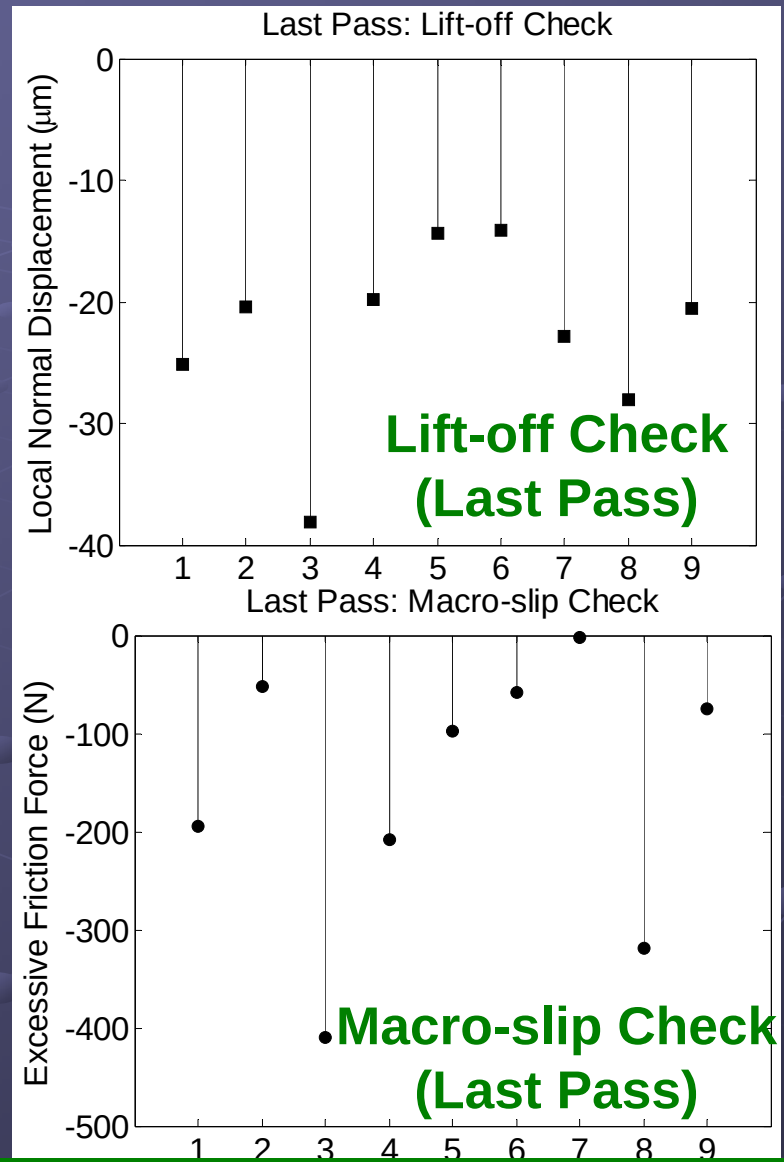
Simulation Example (3)





Simulation Example (4)



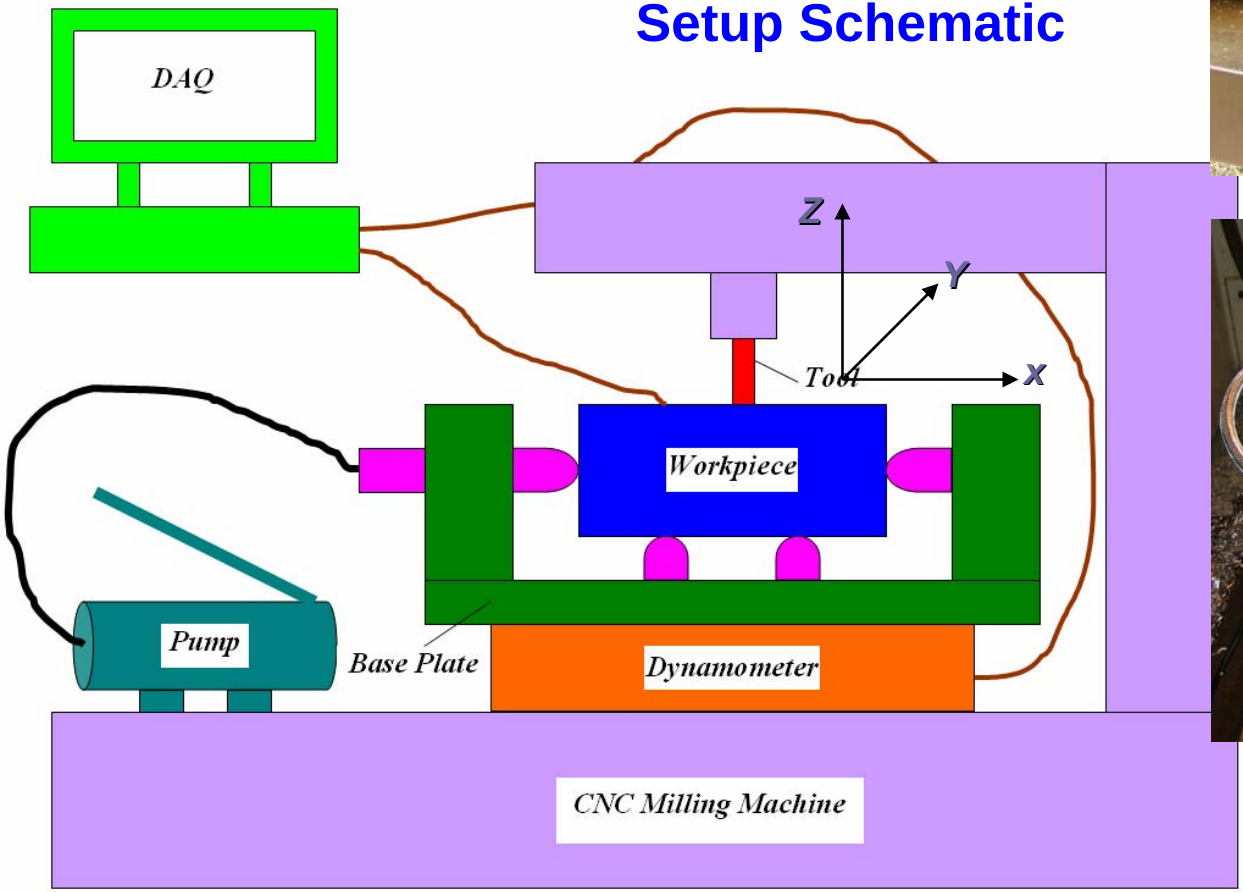


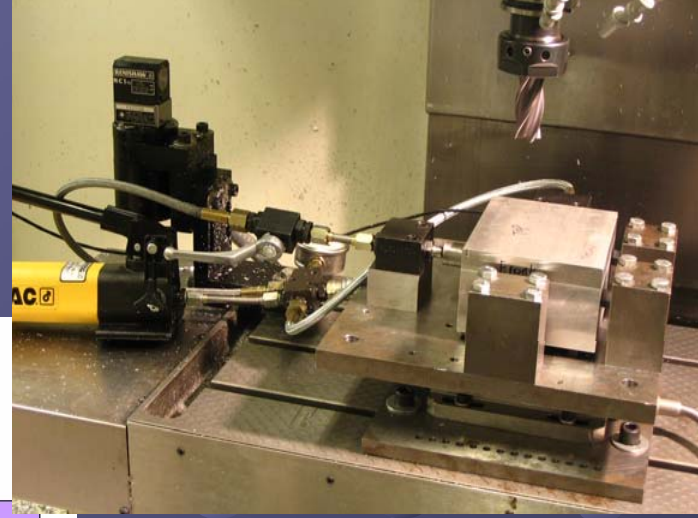
FC = [5261.3, 2864.4, 3310.1] (N)

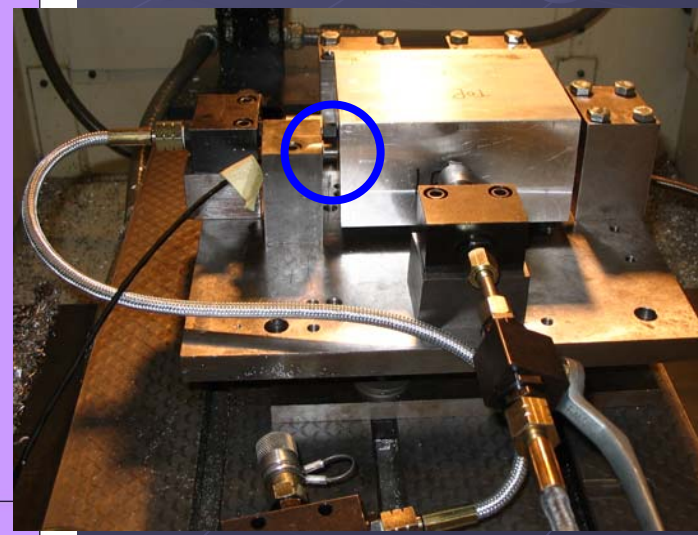
FC = [1713.1, 1961.8, 1139.9] (N)

Experimental Validation (1)

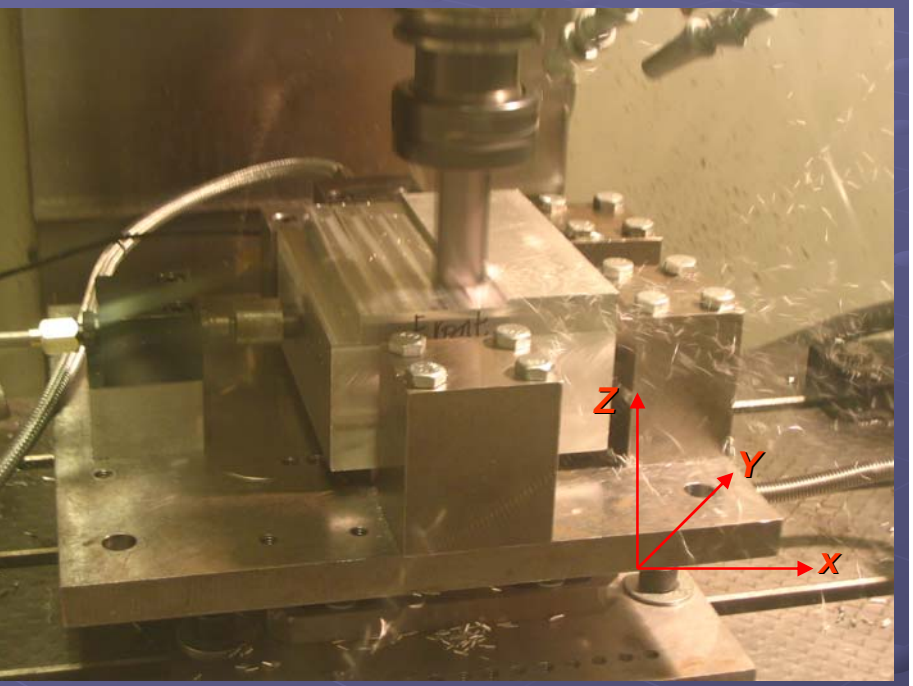
Setup Schematic

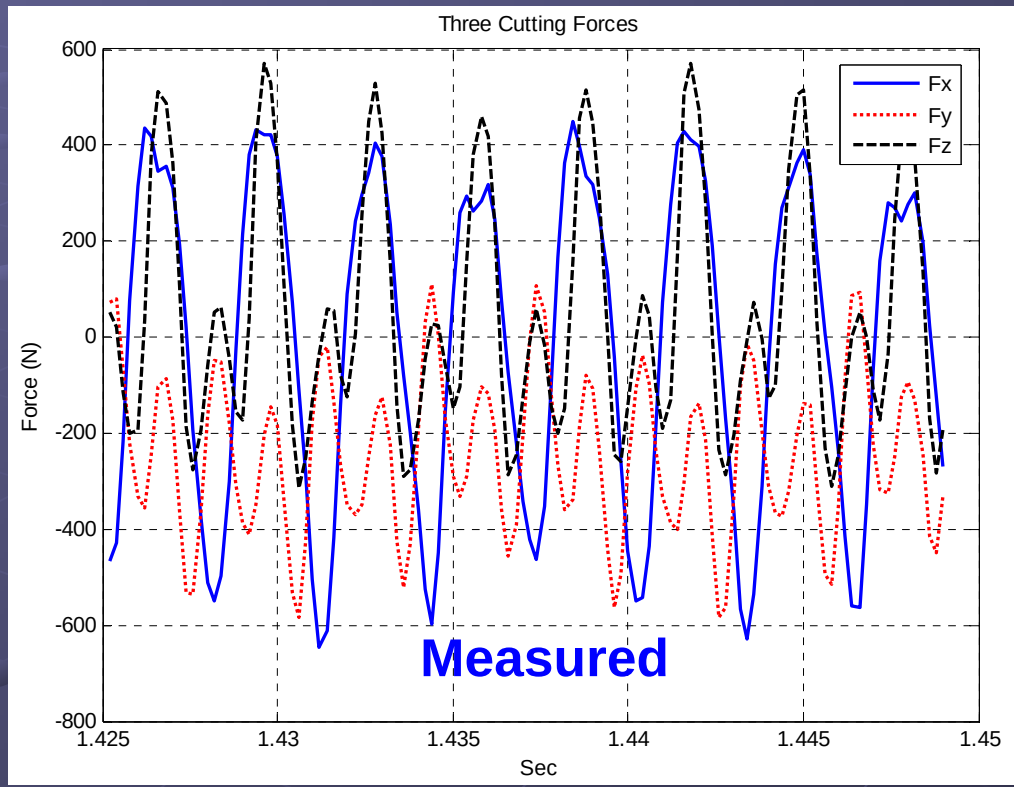






Experimental Validation (2)





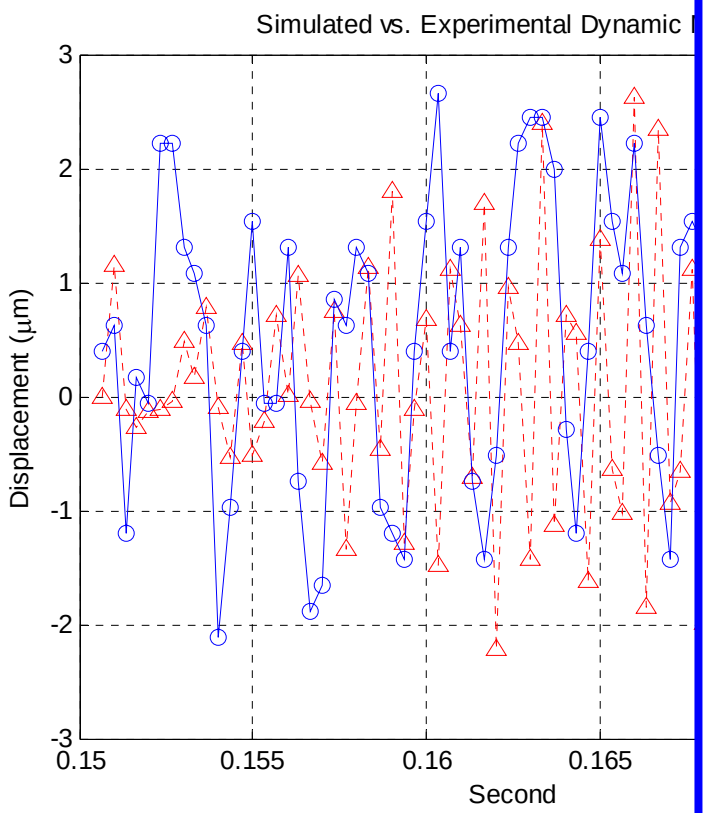
	Workpiece	Fixture Elements
Material	7075-T6 Aluminum	Hardened Steel
Density (kg/m^3)	2700	-
Young's modulus (GPa)	70.3	201
Poisson's ratio	0.354	0.296
Yield Strength (MPa)	500	-

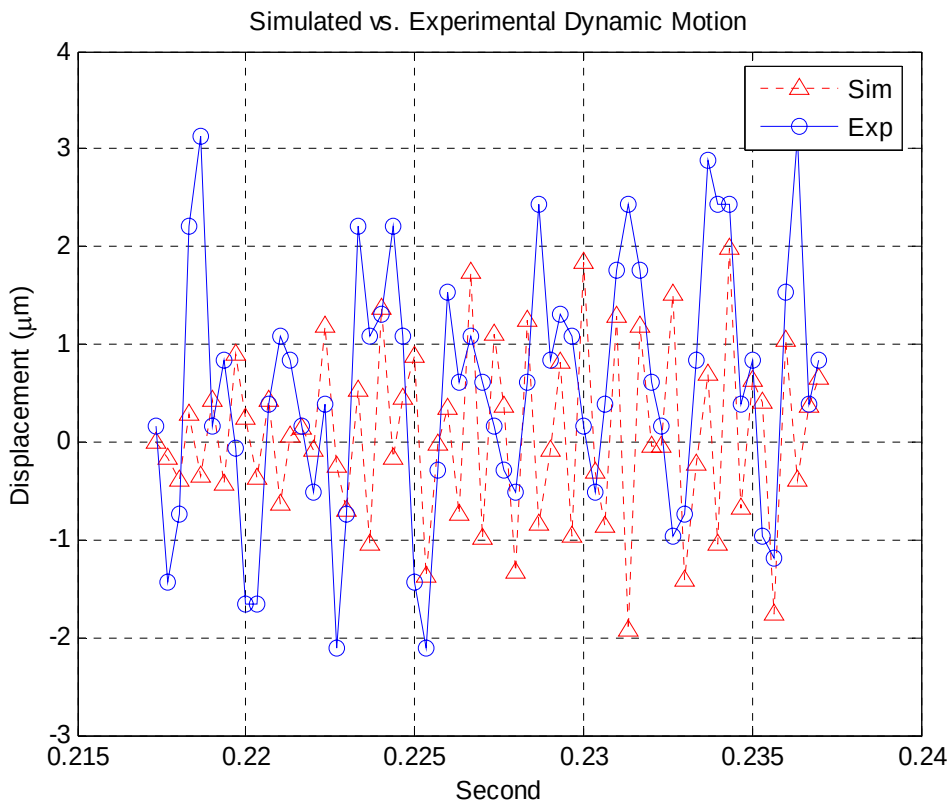
Spindle Speed (rev/min)	Feed Rate (inch/min)	Axial Depth (inch)	Radial Depth (inch)	Clamping (psi)
5000	80	0.16	0.75	1500

(End mill: coated HSS, 1 inch, 4-flute)

Experimental Validation (3)

Sampling Rate = 3000 pts/sec

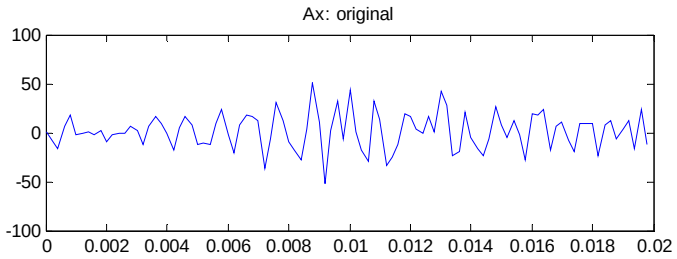


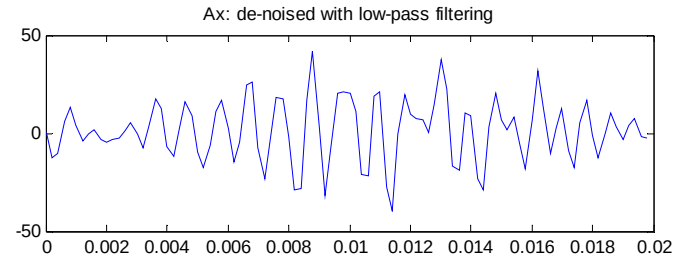


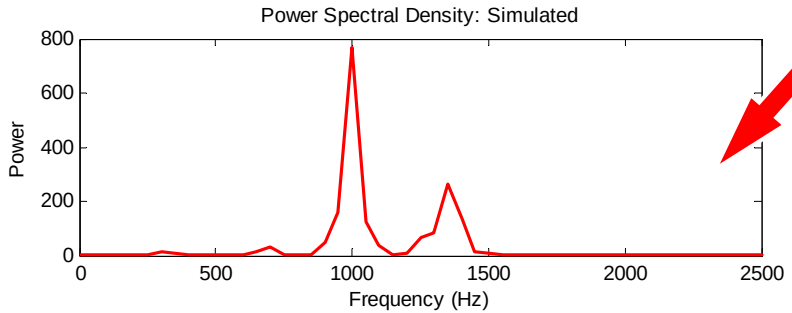
Dynamic displacement of a surface point measured by eddy current sensor

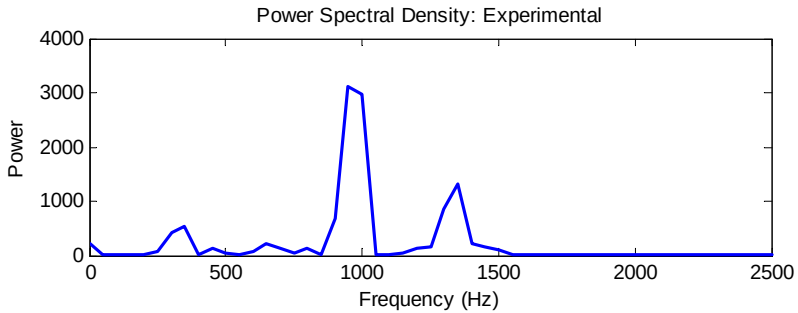
Experimental Validation (4)

Acceleration – Data De-noising
Sampling Rate = 5000 pts/sec

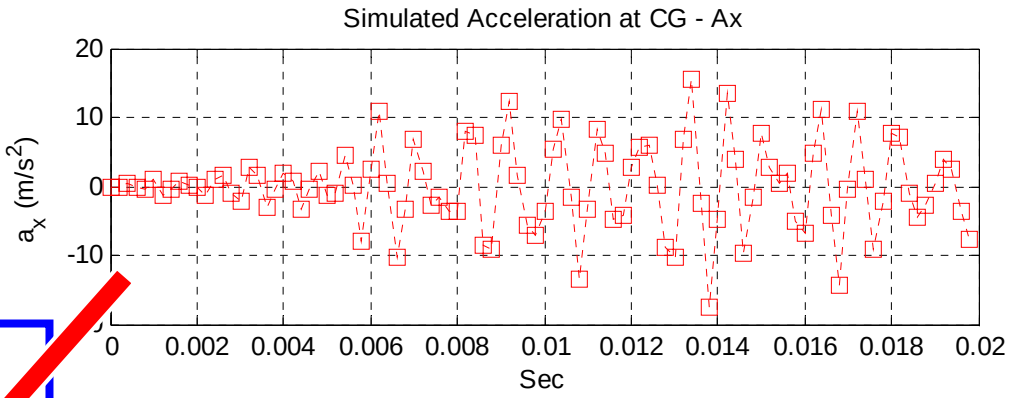


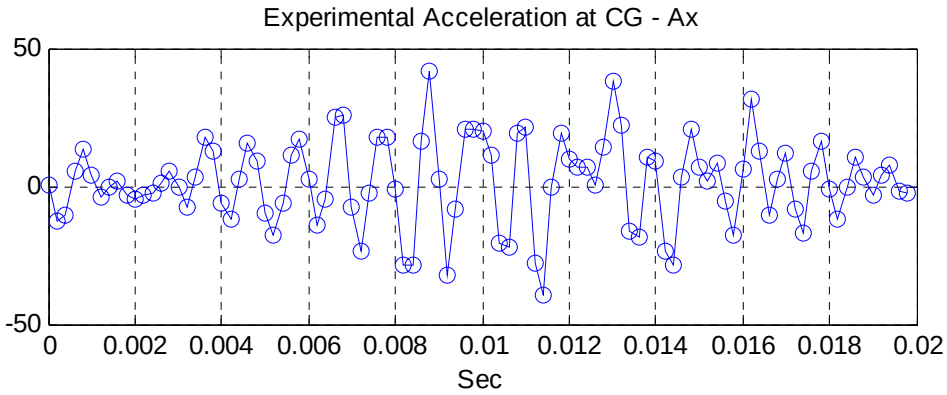






Acceleration @ CG: Simulated vs. Experimental





Conclusions

- A fixture-workpiece system presents significant dynamics during machining. Proper fixture design requires dynamic modeling.
- Material removal affects fixture-workpiece dynamics significantly.
- Dynamic motions of simulated and physical fixture-workpiece systems present similar frequency content.
- Experimental workpiece motion is larger than simulated workpiece motion because actual system is more flexible.

Acknowledgment

This research was supported by a grant from the National Science Foundation (DMII-0218113).